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INTRODUCTION

This volume of the *Guidelines for the safe use of wastewater, excreta and greywater* presents information on the health risks associated with pathogens that occur in human excreta and greywater when used in agriculture. It also presents health protection measures, including technical barriers and best practices to minimize these risks. The Guidelines are based on the development and use of health-based targets. Health-based targets establish a goal of attaining a certain level of health protection in an exposed population. This volume furthermore includes evidence on the fertilizing value of treated excreta, relates their use to sustainability criteria, outlines planning, prevention and implementation strategies and puts their safe handling in a legal, institutional and economic framework. Any possible adverse impacts will be weighed against the health and environmental benefits of recirculating nutrients to arable land. Positive health impacts, such as the contribution to better nutrition and the impact on household food security, especially for the poor, need to be considered in this context.

The poor bear the heaviest burden of diseases transmitted through faecal–oral pathways, which include contaminated water and improper excreta disposal. Therefore, the positive health outcome of these Guidelines is potentially greatest for the poorest members of society, reflecting a social equity dimension. A significant amount of human excreta is used in subsistence agriculture. Although the main focus of the Guidelines is on small-scale systems, their scope is not limited to these.

This volume of the *Guidelines for the safe use of wastewater, excreta and greywater* is structured as outlined in Figure 1.1.

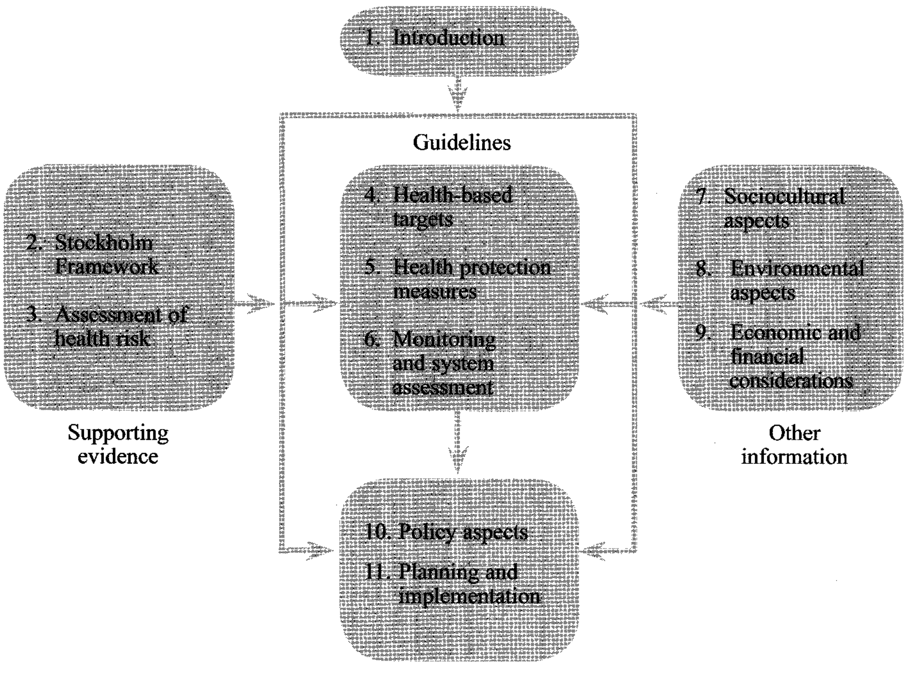

Figure 1.1
Structure of Volume 4 of the *Guidelines for the safe use of wastewater, excreta and greywater*

Chapter 1 presents the objectives and introduces some conceptual issues; it also describes the target audience, the driving forces behind excreta and greywater use, the resource value and the Millennium Development Goals (MDGs). Chapter 2 provides an overview of the Stockholm Framework. Chapter 3 provides the epidemiological, microbiological and risk assessment bases for the Guidelines. Chapters 4 and 5 present health-based targets and health protection measures, including technical components, crop restrictions, agricultural methods, human exposure control, hygiene education and health care aspects, while chapter 6 provide practical guidance on monitoring and system assessment. Chapters 7, 8 and 9 provide background information on sociocultural, environmental and economic and financial aspects. The policy, institutional and legal frameworks are covered in chapter 10, and planning and implementation procedures are presented in chapter 11.

1.1 Objectives and general considerations

The primary objective of these Guidelines is to protect the health of individuals and benefit the health status of communities by the safe use of excreta and greywater in a range of agricultural applications. The Guidelines consider the positive health outcomes of this use (such as its contribution to better nutrition and food security), without presenting these as trade-offs.

To this end, the Guidelines describe recommended reasonable minimum safe practice requirements and system performance to protect the health of the people using excreta and greywater, local communities and the consumers of products grown with them. The Guidelines support the development and implementation of risk management strategies. The required level of health protection can be achieved by using a combination of management approaches (e.g. handling and crop restriction, human exposure control) and quality targets to arrive at the specified health outcome. Thus, the guidance provided concerns both good handling practices and quality speculations and may include:

- a level of management;
- a concentration of a constituent that does not represent a significant risk to the health of members of important user groups;
- a condition under which such exposures are unlikely to occur; or
- a combination of the last two.

The Guidelines relate to an integrated risk management framework (see the Stockholm Framework in chapter 2) applied from the point of generation to consumption of products grown with excreta or greywater. The approach followed in these Guidelines is intended to lead to national standards and regulations that can be readily implemented and enforced and are protective of public health. It is essential that each country review its needs and capacities in developing a regulatory framework. In order to define national standards and procedures, it is necessary to consider the Guidelines in the context of local environmental, social, economic and cultural conditions (WHO, 2004a). Successful implementation of the Guidelines will require a broad-based policy framework that includes positive and negative incentives to alter behaviour and monitor and improve situations. This will require significant efforts in intersectoral coordination and cooperation at national and local levels and the development of suitable skills and expertise.

In some situations, it will not be possible to fully implement the Guidelines at once. The Guidelines allow incremental implementation. The greatest threats to health should be given the highest priority and addressed first. Over time, it should be possible to adjust the risk management framework to strive for the continual improvement of public health.

Ultimately, the judgement of safety — or what is a tolerable level of risk in particular circumstances — is a matter in which society as a whole has a role to play. The final judgement as to whether the benefit from using any of the Guidelines and guideline values as national or local standards justifies the cost is for each country to decide, in the context of national public health, environmental and socioeconomic realities and international trade regulations. The final judgement on safety standards and procedures is a matter for broad public consultation and should result from a transparent and accountable political decision-making process.

1.2 Target audience and definitions

These Guidelines are targeted at decision-makers and regulators in World Health Organization (WHO) Member States who are responsible for setting the framework for, planning and implementing activities in sanitation-related areas. It is hoped that these Guidelines will also be useful to all those with a stake or interest in the safe use of excreta and greywater, public health and water and waste management, including environmental and public health scientists, educators, farmers, researchers, engineers, community planners, policymakers and regulators.

The health hazards linked to the agricultural use of excreta and greywater vary with the distribution of pathogens, the local transmission and exposure pathways and the capacity of health services to deal with them. The pathways are closely related to handling practices in the chain from the producer to the use, including ingestion of contaminated food products. The responsibility for minimizing health risks lies with the direct users of excreta and greywater, with the planners and managers of systems where excreta and greywater are applied and with the local and national regulatory authorities that set standards for norms and procedures. Nongovernmental organizations and special interest groups also have an important role to play in helping local communities to maximize the reuse of valuable resources while ensuring that health risks are reduced to a minimum.

In the context of these Guidelines, "excreta" refers to faeces and urine, but also to excreta-derived products, such as faecal sludge and septage (for definitions of terms used in the Guidelines, see Annex 1). Sludge derived from the treatment of municipal or industrial wastewater is not included in these guidelines. The main focus of these Guidelines is the prevention of infectious disease transmission, and health issues associated with exposure to chemicals are discussed only in broad terms.

"Greywater" is defined as wastewater from the kitchen, bath and laundry, excluding wastewater from toilets, and therefore generally contains lower concentrations of excreta, except in specific situations as a result of infant care or where anal cleansing water is combined with the greywater. Greywater is used mainly for irrigation, but health issues are also associated with the use of greywater for other purposes, such as toilet flushing, service water or groundwater infiltration.

1.3 International guidelines and national standards

1.3.1 National standards

WHO Guidelines are intended to provide a consistent level of health protection in different settings, and they should be adapted for implementation under specific environmental, sociocultural and economic conditions at the national level or below. In some cases, countries may choose to develop different standards for products consumed locally and for products destined for export. Wherever lower national standards are set, based on a locally adopted level of tolerable risk (see chapter 2 for a further discussion of tolerable risk), the incidence of diarrhoeal or other diseases needs to be accounted for.

1.3.2 Food exports

The Guidelines can be adapted based on local conditions, except in relation to the rules that govern international trade in food, which have been agreed during the Uruguay Round of Multilateral Trade Negotiations and apply to all members of the World Trade Organization (WTO). With regard to food safety, rules are set out in the Agreement on the Application of Sanitary and Phytosanitary Measures. According to this, WTO members have the right to take legitimate measures to protect the life and health of their populations from hazards in food, provided that the measures are not unjustifiably restrictive of trade (WHO, 1999). There are documented cases where the import of contaminated vegetables has led to disease outbreaks in recipient countries. Pathogens can be introduced into communities lacking immunity, resulting in important disease outbreaks (Frost et al., 1995; Kapperud et al., 1995). Guidelines for the international trade of excreta-fertilized and wastewater-irrigated food products therefore need to be based on sound scientific risk management principles.

WHO Guidelines for the safe use of excreta and greywater in agriculture are based on a risk analysis approach that is recognized as the fundamental methodology underlying the development of food safety standards that both provide adequate health protection and facilitate trade in food. Adherence to the WHO Guidelines will help to ensure the international trade of safe food products in the case of export of excreta-fertilized or greywater-irrigated food products.

1.4 Factors that affect sustainability in sanitation

Sustainable development, as defined in the Report of the World Commission on Environment and Development (WCED, 1987), is development that "meets the needs of the present generation without compromising the ability of future generations to meet their own needs." From both a sustainability and a public health perspective, increasing access to adequate sanitation and promoting the adoption by individuals and communities of key hygienic behaviours are first priorities.

Within the scope of the *Guidelines for the safe use of wastewater, excreta and greywater*, sustainability can be described as the ability to plan and manage the use of excreta and greywater in agriculture as important resources in such a way that human health is not compromised, nutrients are recycled for food production and negative impacts on water resources or the environment are avoided. Sustainability needs to be defined in relation to the interaction of users, organizational structure and technology, with a range of important criteria: health and hygiene, environmental and resource use, economy, sociocultural aspects and use and technology function. These aspects should be addressed with appropriate policies and within a conducive legal and regulatory framework; they are covered in different parts of the Guidelines.

1.4.1 Health and hygiene

The process of reducing disease burdens through improved sanitation is associated with the determinants of sustainability and is closely related to hygiene, behavioural change and proper access to and use of water and sanitation facilities. Focusing on just the provision of sanitation hardware will not result in sustainable change and will therefore not have a lasting impact on the health status of communities. Health aspects of excreta and greywater use are further dealt with in chapters 3 and 5.

1.4.2 Environment and resource use

Minimizing the negative impacts of excreta and greywater on surface water and groundwater and making more efficient use of the nutrient resources that they contain for crop and energy production will directly contribute to environmental sustainability. The environment will most importantly benefit from the treatment and safe use of excreta and greywater in terms of:

- recycling of water and nutrient resources;
- reduction of pressure on freshwater resources;
- reduction of downstream pollution from the discharge of wastes;
- reduction of potential environmental impacts from various chemicals (among others, endocrine disruptors, pharmaceuticals and their residues, which partly adsorb to soil particles and/or biodegrade in the soil, reducing the environmental impact on waters).

Environmental aspects of excreta and greywater use are further discussed in chapter 8.

1.4.3 Economy

Economic aspects of sanitation are important at both national and household levels. At the national level, planners want to ensure optimal cost-effectiveness of investments in hygiene and sanitation options. These investments should give substantial economic returns in health benefits and time savings (Hutton & Haller, 2004). The cost–benefit of reducing adverse health and other impacts downstream as a result of better wastewater treatment and/or reducing waste discharges into surface waters has not been estimated but is likely to be as important.

Several studies have indicated that it is more cost-effective to provide funding for creating sanitation and hygiene demand through promotion than to heavily subsidize sanitation hardware (Cairncross, 1992; Wright, 1997; Samanta & van Wijk, 1998; Kolsky & Diop 2004). Most costs associated with gaining access to sanitation are incurred at the household level. Consumers want products that are durable and that will not cost a lot to operate and maintain. It is unlikely that sanitation will become sustainable unless local resources are in focus, where people can make a living supplying services to those in need (Kolsky & Diop, 2004). Economic aspects are further discussed in chapter 9 and in relation to institutional and legal aspects in chapter 10.

1.4.4 Sociocultural aspects and use

Sociocultural factors are fundamental for sustainability. A sanitation facility without appeal will not be used. Use is linked to access and convenience factors, but is also governed by social, cultural and religious beliefs. For girls and women, safe access is a major concern. The perception of ownership or responsibility is crucial and will affect, for example, the cleanliness of the facilities and, ultimately, their long-term success. Sociocultural issues concerning the use of excreta and greywater are further discussed in chapter 7.

1.4.5 Technology function

Technology function and selection contribute importantly to aspects of sustainability. Technologies selected for the safe use of excreta and greywater should meet all of the following sustainability criteria, accounting for robustness and variabilities in load:

- Health – technologies should provide inherent individual and public health protection;
- Environment – technologies should prevent contaminants from reaching groundwater and surface water supplies and provide other environmental protection;
- Economy – technologies should be cost-effective and available in a range of options that accommodate different levels of affordability, and it should be possible to upgrade or improve them as more resources become available;
- Sociocultural – technologies should be compatible with local values and beliefs and designed with all potential users in mind.

Excreta and greywater treatment technologies, handling and use are further discussed in chapter 5.

1.5 Driving forces

Driving forces behind the increased use of excreta and greywater in agriculture worldwide include:

- increasing water scarcity and stress, and degradation of freshwater resources resulting from improper disposal of excreta and greywater;
- population increase and related increased demand for food and fibre;
- a growing recognition of the resource value of excreta and greywater and the nutrients they contain;
- the MDGs, especially the goals for ensuring environmental sustainability and for eliminating poverty and hunger.

1.5.1 Water scarcity, stress and degradation

It is estimated that within the next 50 years, more than 40% of the world's population will live in countries facing water stress or water scarcity. In 1995, 31 countries were classified as water-scarce or water-stressed, and it is estimated that 48 and 54 countries will fall into these categories by 2025 and 2050, respectively. These numbers do not include people living in arid regions of large countries where sufficient water is poorly distributed — e.g. China, India and the United States of America (China is predicted to reach water scarcity by 2050 and India by 2025) (Hinrichsen, Robey & Upadhyay, 1998). Growing competition between agricultural and urban areas for high-quality freshwater supplies, particularly in arid, semi-arid and densely populated regions, will increase the pressure on this resource.

Excreta and greywater can be treated and used close to their origin, either on site or in decentralized treatment systems. This prevents their discharge into surface waters, thus reducing downstream microbial and chemical contamination. It also reduces the costs of developing infrastructure for elaborate conveyance systems (e.g. sewer networks).

Additionally, the "polluter pays" principle is starting to take hold in many places, forcing upstream users to treat their wastes to higher standards before discharging them into water bodies. Previously, the additional costs of water treatment or loss of ecosystem services (e.g. destruction of fisheries or loss of aesthetic value) were passed on to downstream water users. Acknowledgement of the concept of integrated water resources management has led to the realization that waste discharges into surface waters have health, environmental and economic implications for downstream users. As this awareness spreads, it will become increasingly difficult to discharge inadequately treated wastes into surface waters. Therefore, treatment and use of excreta and greywater closer to the point at which they are generated become a more attractive option.

1.5.2 Population growth and food production

Over the next 50 years, most population growth is expected to occur in urban and periurban areas in developing countries (United Nations Population Division, 2002). For example, a majority of the 19 cities for which the most rapid growth is predicted between 2000 and 2015 (with populations expected to more than double) are in chronically water-short regions of the developing world (United Nations Population Division, 2002).

The growth of urban populations, especially in developing countries, will lead to several new challenges:

- greater populations will generate more wastes, especially in and around cities;
- on-site waste disposal will be more difficult in many densely populated areas;
- urban agriculture will play a more important role in supplying food to city dwellers. Excreta and greywater will become increasingly important as inputs.

Excreta and greywater can help to improve food production, especially for subsistence farmers who otherwise might not be able to afford artificial fertilizers. The use of greywater for irrigating home gardens may also help to relieve malnutrition and food insecurity at the household level by providing a steady supply of water for crop irrigation, allowing the year-long production of vegetables.

The use of treated and source-separated faeces and urine has been suggested as suitable for urban agriculture. Wastewater is used already to a large extent in these applications. Treated excreta would potentially pose fewer health risks in these types of applications. Esrey (2001) has summarized the impact of excreta use in relation to nutrients in urban areas.

Eighty per cent of the world's natural food resources are converted into waste and disposed of (Smit, 2000). According to predictions for 2015, about 26 cities in the world are expected to have a population of over 10 million people, which implies the need to import an estimated 6000 tonnes of food each day (FAO, 1998). More than 50% of the absolute poor live in urban areas and spend much of their income on food. Their dietary intakes are nutrient limited, and urban residents in developing countries have a lower energy intake than their rural counterparts. Yet poor urban dwellers will not be able to afford imported food.

Lowering the costs of inputs and producing food closer to where people live can reduce food production costs. Urban agriculture and home gardening can produce more food per unit space, because food can be grown on roofs, on walls and in and around buildings. Urban agriculture has enjoyed a revival in the past few decades (Smit, Ratta & Nasr, 1996). In greater Bangkok, 60% of the land is under cultivation. The demand for food by consumers and for water and nutrients by producers reconnects resources and wastes in a safe, non-polluting and economic fashion. Growing food closer to consumers also strengthens the livelihood of local communities.

Recovery and recycling of nutrients from human excreta and other organic matter provide complete nutrition for plants. Access to affordable and more nutritious food will increase and post-harvest food losses will be reduced if food is grown and consumed locally. This represents a saving in water as well as nutrients.

When food is grown farther away from population centres, not only does it cost more, but valuable micronutrients are less likely to reach consumers, particularly people with little income. Urban farming and home gardening, on the other hand, can result in better diets, improving macro- and micronutrient intakes as well as the nutritional status of vulnerable groups, such as women, children, the elderly and the disabled (Maxwell, Levin & Csete, 1998).

1.5.3 Excreta and greywater as resources

Excreta and greywater contain nutrients and water, which make them valuable resources. The use of excreta and greywater in agriculture, aquaculture and other settings reduces the need for artificial fertilizers and is important for nutrient recycling. Some studies indicate that the world's supply of readily available phosphorus is limited and will run out in 150 years (Rosemarin, 2004). Excreta are an accessible source of important plant nutrients, such as phosphorus, nitrogen and potassium. Excreta use can help to reduce the mining of finite phosphorus reserves and energy expended to create artificial fertilizers. Greywater is mostly used for irrigation, as service water or sometimes for groundwater recharge at a local scale. Its use helps reduce the demand for freshwater supply and mitigates the stress on water resources.

Excreta quantities and composition

Annually, about 130 million tonnes of fertilizers are sold globally, 63% of which are sold in the developing world. Of this quantity, 78 million tonnes are nitrogen and 13.7 million tonnes phosphorus. The rest represents potassium, sulfur and micronutrients. The excreta from 6 billion persons contain 27 million tonnes of nitrogen and 3 million tonnes of phosphorus. This means that one third of the world's mineral nitrogen use could in theory be replaced by nitrogen from excreta. Similarly, 22% of the world's use of mined phosphorus could be replaced by phosphorus from excreta.

The major plant nutrients nitrogen, phosphorus and potassium are found in human excreta and thus also in domestic wastewater (Figure 1.2), but the contents will vary depending on the food intake. Greywater will mainly recycle water and supplies only minor amounts of nutrients.

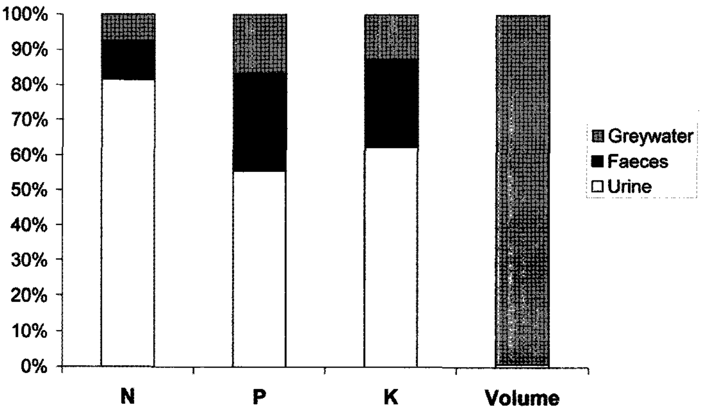

Figure 1.2

Content of major plant nutrients and volume in domestic wastewater in Sweden. The daily mean excretion per person and per day is 13 g nitrogen (N), 1.5 g phosphorus (P) and 4 g potassium (K) in a volume of 150–200 litres, including greywater (Vinnerås, 2002).

Mass balance and content of macronutrients in excreta

The nutrient content in urine and faeces depends directly on the amounts and quality of food consumed. Children need nutrients to grow; in adults, however, food consumption is mainly for energy, and only minor amounts of nutrients are retained and accumulated in the body. Almost all consumed plant nutrients will therefore leave the human body in excreta. Even during adolescence, accumulation of nutrients in the body is negligible, calculated to be less than 2% of the consumed nitrogen between the ages of 3 and 13.

Since most nutrients leave the human body in excreta, excreted plant nutrients can be calculated from food intake, on which information is readily available. Based on statistics from the Food and Agriculture Organization of the United Nations (FAO) (http://www.fao.org) on the available food supply in different countries, calculations have been made of amounts and macronutrient content of excreta (Jönsson & Vinnerås, 2004). Table 1.1 provides default values for these parameters in Sweden.

Table 1.1 Swedish default values for excreted mass and nutrients

Parameter	Unit	Urine	Faeces	Toilet paper	Blackwater (urine + faeces)
Wet mass	kg/person per year	550	51	8.9	610
Dry mass	kg/person per year	21	11	8.5	40.5
Nitrogen	g/person per year	4000	550		4550
Phosphorus	g/person per year	365	183		548

Source: Vinnerås (2002).

The estimated average amounts of excreta, food intake (according to FAO statistics) and nutrient content in different foodstuffs are used in a relationship (Equations 1 and 2) between food intake (according to FAO) and the excretion of nitrogen and phosphorus:

$$N = 0.13 \times \text{total food protein} \qquad \textbf{Equation 1}$$

$$P = 0.011 \times (\text{total food protein} + \text{vegetal food protein}) \qquad \textbf{Equation 2}$$

These equations can be used to estimate the average excretion of nitrogen and phosphorus in different countries; see examples in Table 1.2. There tends to be greater variability in values for potassium.

The total per capita annual excretion reported by Gao et al. (2002) for China was 4.4 kg of nitrogen and 0.5 kg of phosphorus, which are in the same range as the figures given in Table 1.2, where the total excretion has been partitioned between urine and faeces.

The relative amounts of nutrients in urine and faeces depend on the diet: digested nutrients are mainly excreted with the urine, whereas undigested fractions are excreted in the faeces. Approximately 88% of the excreta nitrogen and 67% of the excreta phosphorus are found in the urine, and the rest are in the faeces. These figures are lower in China, where the urine contains approximately 70% of the excreta nitrogen and 25–60% of the phosphorus (Gao et al., 2002).

Digestibility also influences the amount of faeces excreted. In Sweden, the amount of faeces excreted is estimated at 51 kg wet mass/person per year (11 kg dry weight) (Vinnerås, 2002). In China, faecal excretion is estimated at 115 kg wet mass/person per year (22 kg dry weight) (Gao et al., 2002).

Table 1.2 Estimated excretion of nutrients per capita in different countries

Country		Excretion rate (kg/person per year)		
		Nitrogen	Phosphorus	Potassium
China, total		4.0	0.6	1.8
	Urine	3.5	0.4	1.3
	Faeces	0.5	0.2	0.5
Haiti, total		2.1	0.3	1.2
	Urine	1.9	0.2	0.9
	Faeces	0.3	0.1	0.3
India, total		2.7	0.4	1.5
	Urine	2.3	0.3	1.1
	Faeces	0.3	0.1	0.4
South Africa, total		3.4	0.5	1.6
	Urine	3.0	0.3	1.2
	Faeces	0.4	0.2	0.4
Uganda, total		2.5	0.4	1.4
	Urine	2.2	0.3	1.0
	Faeces	0.3	0.1	0.4

Source: Jönsson & Vinnerås (2004).

The concentration of nutrients in the excreted urine depends on the nutrients and liquid intake, level of personal activity and climate conditions. The liquid intake is in the range of 0.8–1.5 litres per person per day (up to 550 litres per person per year) for adults and about half that amount for children in Europe (Lentner, Lentner & Wink, 1981), but it may be much higher due to climate or activity level. Similar amounts have been reported for China: 1.6 litres per person per day (580 litres per person per year) (Gao et al., 2002). Excessive perspiration results in concentrated urine, while consumption of large amounts of liquid dilutes the urine.

Use of urine as fertilizer

Urine is rich in nitrogen and can be used for fertilizing most non-nitrogen-fixing crops after proper treatment to reduce potential microbial contamination. Crops with a high nitrogen content that respond well to nitrogen fertilization include spinach, cauliflower and maize. Direct use of urine as a plant fertilizer will entail the most efficient use of nutrients, but addition of urine to improve composting of carbon-rich substrates is another possibility (although it may result in large ammonia losses). The nutrients in urine are in ionic form, and their plant availability and fertilizing effect compare well with those of chemical (ammonium- and urea-based) fertilizers (Kirchmann & Petterson, 1995; Johansson et al., 2001). When the nitrogen content of collected urine is unknown, a concentration of 3–7 g of nitrogen per litre at excretion can be used as a default value (Jönsson & Vinnerås, 2004). On a yearly basis, the amount of nitrogen produced per person equals 30–70 kg, supporting one crop on 300–400 m^2, but up to 3–4 times this level may be an optimal application strategy.

The achieved yield varies depending on the soil conditions. As with chemical fertilizers, the effect is lower on soil poor in organic content. Under these conditions, soil fertility may benefit from using both urine and faeces or other organic fertilizers alternatively applied in consecutive years and for different crops. Urine can be applied either undiluted or diluted with water, preferentially just before sowing or during the initial plant growth. Once the crop enters its reproductive stage, nutrient uptake is low, and nutrients are mainly relocated within the plant (Marschner, 1997). Plants with inefficient or small root systems (e.g. carrots, onions and lettuce) will benefit from repeated applications during the cultivation period (Thorup-Kristensen, 2001). The test results of the use of urine as a fertilizer for barley in Sweden are shown in Box 1.1.

The best fertilizing effect is obtained when the urine is directly incorporated into the soil after application; shallow incorporation is sufficient (Rodhe, Richert Stintzing & Steineck, 2004). Direct incorporation also minimizes ammonia losses to the air. Surface application generally gives a nitrogen loss above 70% due to ammonia volatilization, and soil incorporation is therefore very important (Morken, 1998).

Trials with different application strategies using urine as a fertilizer for leeks gave a threefold yield increase (Båth, 2003). Application either in two doses or divided into smaller doses applied every 14 days gave the same yield and nutrient uptake (Table 1.3). The strategy used in West Africa involves the frequent application of small amounts of urine in order to avoid leaching. Extensive trials have been performed on various vegetables in Zimbabwe (Morgan, 2004). Results confirm the experience that urine is a quick-acting fertilizer that can be used for most vegetables.

Table 1.3 Results of a field trial using human urine as a fertilizer for leeks

Treatment[a]		Nitrogen application rate (kg/ha)[b]	Yield (t/ha)[b]	Nitrogen yield (kg/ha)[b]
A	Urine every 14 days	150	54	111
B	Urine twice	150	51	110
C	Urine every 14 days + extra potassium	150	55	115
D	Unfertilized	0	17	24

[a] No statistically significant difference between treatments A, B and C.
[b] kg/ha = g/10 m^2; t/ha = kg/10 m^2.
Source: After Båth (2003).

Use of faeces as fertilizer

Faeces may contain high concentrations of pathogens, and appropriate treatment is therefore crucial to ensure its safe use. The total amount of nutrients excreted is lower in faeces than in urine, but the concentrations of (especially) phosphorus and potassium are higher in faeces than in urine. It is these two elements that may significantly increase the crop yield (Morgan, 2003). The content of organic matter in faeces also increases the water-holding and ion-buffering capacities of soils, which is of importance for improving soil structure and stimulates the microbial activity. The fertilizing effect of faeces is more variable than that of urine, since the proportion of nitrogen in mineral form and the content and properties of the organic matter vary depending on the treatment applied.

Faecal compost applied together with urine may have advantages, since the former conditions the soil and the latter provides rapidly accessible nitrogen. Incineration of faeces results in ash with high contents of phosphorus and potassium as well as micronutrients, but nitrogen and sulfur are lost to the atmosphere. Ash in general (which may also be added to the faeces) also increases the pH and the buffering capacity of the soil. The pH increase is especially important on soils with very low pH (4–5) and to get the full benefit from fertilizing with, for example, urine, as shown on experimental plots in Zimbabwe (Morgan, 2005).

Box 1.1 Urine as fertilizer for barley in Sweden

Urine was tested as a fertilizer on barley in Sweden during 1997–1999 (Johansson et al., 2001; Rodhe, Richert Stintzing & Steineck, 2004). Results showed that the nitrogen effect of urine corresponded to about 90% of that of equal amounts of ammonium nitrate mineral fertilizers (Figure 1.3). The urine was spread before sowing with a conventional spreader for liquid manure (Figure 1.4).

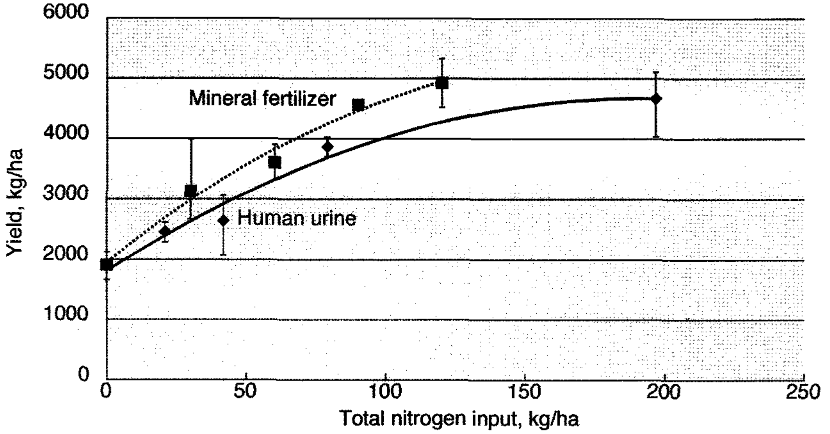

Figure 1.3
Results from field trials with urine as fertilizer for barley, 1999

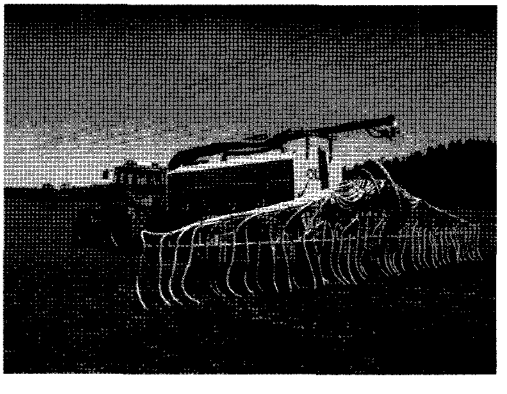

Figure 1.4
Conventional slurry spreader used for application of urine

Faecal compost can be applied as a complete phosphorus–potassium fertilizer or as a soil improver. Approximately 40–70% of the organic matter and somewhat less of the nitrogen are lost through biological activity and volatilization. Most of the remaining nitrogen will become available to plants during degradation. This slow process improves the water-holding and buffering capacity of the soil. The phosphorus is also partly, but to a lesser extent, bound in organic forms, whereas the potassium is mainly in ionic form and readily available to plants. In anaerobic digests, approximately the same proportion of organic matter is degraded as in composting, but the mineralized nitrogen remains within the digested residue and 40–70% of the nitrogen is in the form of ammonium, which is readily available to plants. The digested residues make up a well balanced, quick-acting and complete fertilizer (Åkerhielm & Richert Stintzing, 2004). Additional substrates, such as animal manure and household waste, are often added to digestion processes, which affects the amount and composition of the residue.

If faeces are dried rapidly and low moisture levels prevail, the loss of organic matter and nitrogen will be small. Compared with composting, dry storage recycles more organic matter and nitrogen to the soil, but the organic matter is less stable. Dried faecal matter is a complete phosphorus–potassium fertilizer, contributing considerable amounts of nitrogen as well.

Treated faeces, in a desiccated, incinerated, composted or mixed form, is preferably applied to and incorporated in the root zone of the soil prior to sowing or planting, because the high content and availability of phosphorus are important for the development of small plants and roots.

The faecal matter from one person is enough to fertilize 200–300 m^2 of wheat at a yield of 3000 kg/ha based on the P content. Where the soil is devoid of phosphorus, 5–10 times the removal rate can be applied. At this application rate, most of the phosphorus will remain and will improve the soil, with significant yield increases and without negative effects from phosphorus or organic matter. Application rates for farmyard manure in agriculture are in the range of 20–40 t/ha. If large amounts of lime or ash are used as additives, a minor risk of negative effects exists at high application rates, due to a high resulting pH (>7.5–8) in the soil. This risk will, however, materialize only at extremely high application rates or if the initial pH of the soil is already high.

In bucket experiments of low-temperature composting of faeces in Zimbabwe, vegetables such as spinach, covo, lettuce, green pepper, tomato and onion were grown in 10-litre buckets with poor local topsoil (Morgan, 2003). Growth was compared between no additions and plants grown in topsoil mixed with an equal volume of humus derived from co-composted human faeces and urine. A dramatic increase in vegetable yield resulted from the addition of the composted faeces and urine mix to poor soil (Table 1.4).

Table 1.4 Average yields in plant trials comparing growth in topsoil only with growth in a mixture consisting of 50% topsoil and 50% Fossa alterna compost

Plant and soil type	Growth period	Yield (g fresh weight) in topsoil only	Yield (g fresh weight) in 50/50 topsoil/Fossa alterna soil	Relative yield improvement rate
Spinach, Epworth soil (n = 6)	30 days	72	546	7.6
Covo, Epworth soil (n = 3)	30 days	20	161	8.1
Covo 2, Epworth soil (n = 6)	30 days	81	357	4.4
Lettuce, Epworth soil (n = 6)	30 days	122	912	7.5
Onion, Ruwa soil (n = 9)	4 months	141	391	2.8
Green pepper, Ruwa soil (n = 1)	4 months	19	89	4.7
Tomato, Ruwa soil	3 months	73	735	10.1

Source: Morgan (2003).

Greywater volume and composition

Greywater production and composition are dependent on sanitary standards, awareness of the need for water conservation, water availability and raw water composition (Lens, Zeeman & Lettinga, 2001; Eriksson et al., 2002). Greywater volume and composition also vary with lifestyle: family size, age of residents, eating habits and detergents used. The main sources of greywater are laundry, bathroom and kitchen. In the following summary, the results of some studies on greywater volume and composition are presented.

Greywater volumes produced may be as low as 20–30 litres per person per day in poor areas where water often is hand-carried from taps (Ridderstolpe, 2004; Winblad & Simpson-Hébert, 2004). When availability increases, the production of greywater increases, but it seldom exceeds 100 litres per person per day in developing countries. In industrialized countries, greywater production is normally in the range of 100–200 litres per person per day (the highest figures are reported from the USA and Canada) and sometimes exceeds 200 litres per person per day (Crites & Tchobanoglous, 1998; Bertaglial et al., 2005). In new housing developments in Europe, where awareness of the need for water conservation is promoted, the per capita daily greywater production is less than 100 litres (Table 1.5).

In general, the concentrations of plant nutrients (nitrogen, phosphorus and potassium) and pathogens of health concern are low in greywater (Ottosson & Stenström, 2003a; Jenssen & Vråle, 2004), due to the fact that the majority of these are found in excreta. Bacterial indicators tend to overestimate the faecal load in greywater because regrowth may occur (Manville et al., 2001); compared with chemical biomarkers, a 100- to 1000-fold overestimation of the faecal load was found (Ottosson & Stenström, 2003a). The microbial contamination of greywater is, however, significant and must be taken into account when calculating risks and selecting treatment methods.

Table 1.5 Examples of greywater production

Location	Greywater production (litres per person per day)	Reference
China, ecological sanitation project	80	EcoSanRes (2005b)
Belgium	85	Bertaglial et al. (2005)
Germany	35–65	Panesar & Lange (2001)
Germany, Eco-village Flintenbreite	60	Ridderstolpe (2004)
Germany, Norway and Sweden, new built house area, water conservation	<100	Ridderstolpe (2004); Winblad & Simpson-Hébert (2004)
Norway, ecovillage	81	Kristiansen & Skaarer (1979)
Norway, student dormitories, water conservation	112	Jenssen (2001)
Sweden, range for ecovillages	66–110	Vinnerås et al. (2006)
Sweden, proposed norm	100	Vinnerås et al. (2006)
Sweden, existing norm	150	Vinnerås et al. (2006)
Europe, northern part	110	Lens, Zeeman & Lettinga (2001)
Australia, western part	112	Department of Health (2002)
USA	200	Crites & Tchobanoglous (1998); Bertaglial et al. (2005)
Developing regions	20–30	Ridderstolpe (2004); Winblad & Simpson-Hébert (2004)
Range	70–275	Otterpohl (2002)

Greywater contributes 10–30% of the total phosphorus input to a combined wastewater system, and the concentrations are governed by the type of detergents (Rasmussen, Jenssen & Westlie, 1996; Vinnerås, 2002; Jenssen & Vråle, 2004). If phosphorus-containing detergents are used, concentrations typically range from 3 to 7 mg/l. If phosphate-free detergents are used, the concentrations are about 1 mg/l. Greywater contributes 10% or less of the total nitrogen content in wastewater, and the nitrogen concentration in greywater is often 10 mg/l or less, prior to treatment (Vinnerås, 2002; Jenssen & Vråle, 2004).

Greywater contains 50% or more of the readily degradable organic matter in household sewage — measured as biological (BOD) or chemical (COD) oxygen demand — but the concentrations are highly variable, depending on household practices. In industrialized countries, excessive amounts of detergents, including shampoos, shower oils, cleansing powders, etc., are common and responsible for substantial BOD input, in addition to grease and oil used in food preparation. In cultures where use of cooking oil is common, the greywater organic content becomes very high and may call for special care when designing treatment systems. If collected separately, the oil and grease can be processed to biodiesel (Zhang et al., 2003), but they can also increase biogas yield in anaerobic digestion. Examples of concentrations of various water quality parameters found in untreated or primary treated greywater are presented in Table 1.6.

The concentrations of nutrients in greywater depend on the per capita mass discharge and the water use. The per capita discharges under Swedish conditions are presented in Table 1.7.

In the sites listed in Table 1.7, phosphorus-containing detergents were used. According to Norwegian studies, the per capita mass discharge of phosphorus is reduced to 0.2 mg/l with phosphorus-free detergents (Jenssen & Vråle, 2004). The major part of the heavy metal load in household wastewater is found in the greywater fraction (Vinnerås, 2002), and concentrations of heavy metals can therefore be expected to be on the same level as in combined household wastewater.

1.5.4 Millennium Development Goals

At the 2002 World Summit on Sustainable Development in Johannesburg, global leaders agreed to adopt a sanitation coverage target — namely, "to halve, by the year 2015, the proportion of people who do not have access to basic sanitation" (United Nations, 2002). Expanding access to and proper use of improved sanitation facilities would have far-ranging positive health consequences and would support meeting the relevant targets of the Millennium Development Goals.

To achieve the sanitation target under MDG7, WHO estimates that 1.9 billion people will need to gain access to improved sanitation by 2015 — 1 billion urban dwellers and 900 million rural dwellers. This figure takes into account the projected population growth. As of 2002, 77% of the unserved worldwide (i.e. 2 billion people) lived in rural areas. Expanding access to basic sanitation in rural areas is an urgent priority (WHO/UNICEF, 2004). A large percentage of population growth, however, is expected to occur in urban and periurban areas (often in slums or informal settlements) in developing countries.

Many of the 2.6 billion people without improved sanitation are among those hardest to reach: families living in remote rural areas and urban slums, families displaced by war and famine and families mired in the poverty/disease trap (WHO/UNICEF, 2004).

Table 1.6 Concentrations of some water quality parameters found in untreated or primary treated (septic tank effluent) greywater

Country/reference	**Parameters**							
	BOD_5 (mg/l)	**COD (mg/l)**	**Suspended solids (mg/l)**	**Total N (mg/l)**	**NH_4 (mg/l)**	**Kjeldahl N (mg/l)**	**Total P (mg/l)**	**Faecal coliforms (log numbers/ 100 ml)**
Canada / Brandes (1978)	149	366	162	11.5	1.7	11.3	1.4[a]	6.2
Norway / Kristiansen & Skaarer (1979)	130	341	35	19	11.5		1.3 (0.42[b])	5.1
USA[c] / Siegrist & Boyle (1981)	178	456	45			15.9	4.4	6.2
Sweden norm / Naturvårds-verket (1995)	187		107	6.7			4 (1.0[b])	
Norway[c] / Rasmussen, Jenssen & Westlie (1996)	116		39	42.2	36.1		3.97	
Australia / Department of Health (2002)	160		115		5.3	12	8	5.2
Norway[c] / Jenssen (2001)	88	277	–	8.8	3.8	4.9	1.0[b]	4–6
Sweden proposed norm / Vinnerås et al. (2006)	260[e]	520		13.6			5.2	
Germany / Li et al. (2004)	73–142			8.7–13.1	2.5		6.8–9.2	4–6
Malaysia[d] / Jenssen et al. (2005)	128	212	75	37	12.6	22.2	2.4	5.8

BOD_5, five-day biological oxygen demand
[a] Excluding laundry.
[b] Phosphorus-free detergents.
[c] BOD_7, seven-day biological oxygen demand, for the Swedish proposed norm.
[d] Septic tank effluent.

In urban and periurban centres, much of the sanitation expansion may be in the form of sewerage (conventional sewerage in urban centres and simplified sewerage in periurban areas or slums). Sewerage systems are expensive to build and maintain and require relatively large volumes of water to function properly (simplified sewerage systems require less water than full sewerage systems). Although sewer systems protect the health of the user, health gains may be limited for the community as a whole, because much of the wastewater is likely to be discharged into water bodies without adequate treatment, thus exposing downstream users to human pathogens through untreated drinking-water, food or contact with contaminated water.

Table 1.7 Greywater volume and concentrations of various water quality parameters in greywater collected from Swedish eco-housing developments compared with Swedish norm values

Parameters	Ekoporten	Gebers	Vibyåsen	Swedish norm	Proposed norm
Volume (litres per person per day)	104	110	66	150	100.0
Dry mass (g/person per day)	59.2	15.1	29.2	20	59.8
BOD_7 (g/person per day)		21.1	27.7	28.0	26.0
COD (g/person per day)		47.9	39.0	72.0	52.1
Nitrogen (g/person per day)	1.7	1.4	0.6	1.0	1.4
Phosphorus (g/person per day)	0.4	0.6	0.5	0.3	0.5
Potassium (g/person per day)	4.0	1.0	0.5	0.5	1.0

BOD_7, seven-day biological oxygen demand

Source: Calculated from Vinnerås et al. (2006).

Therefore, if effective treatment were available at the household level, prior to discharge of waste into the environment or use, the health of downstream users would be better protected.

Poverty has long been recognized as one of the primary impediments to sustainable development. In many countries, poor subsistence farmers do not have access to water resources and may not have money to buy fertilizers. The use of excreta and greywater in agriculture has the potential to affect poverty positively in several ways:

- improved household food security and nutritional variety, which reduce malnutrition;
- increased income from sale of surplus crops (the use of excreta and greywater may allow cultivation of crops year-round in some locations);
- money saved on fertilizer, which can be put to other productive uses.

However, increased poverty may also result when poor management and dangerous practices lead to negative public health outcomes.

The use of excreta and greywater in agriculture is therefore a key development issue and is at the centre of the sanitation debate. Poor households spend a larger percentage (50–80%) of their income on food and water than do households that are better off (Lipton, 1983; World Food Programme, 1995). Without access to resources such as excreta or greywater, many poor families would not be able to meet their nutritional needs or would spend more money on food and less on other health-promoting activities, such as primary health care or education.